Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 14 (2016) 804 – 810

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th Transport Research Arena April 18-21, 2016

Technological sides of crack sealing in asphalt pavements

Roman Gnatenko [a], Kateryna Tsyrkunova [a,]*, Valeriy Zhdanyuk [b]

[a]*Ukrainian Road Investments,Antonovycha str., 51, Kyiv, 03150, Ukraine*
[b]*Kharkiv National Automobile and Highway University, Road Construction Department, Petrovskogo str., 25, Kharkiv, 61002, Ukraine*

Abstract

Cracks are one of the most widespread modes of deterioration of asphalt concrete road pavements in Ukraine. The main cause of cracking in asphalt pavements is tensile stress due to loads from vehicles as well as abrupt temperature decease and its significant gradients in winter. Observations indicate that joint influence of the above-mentioned factors results in cracking in relatively thin asphalt overlays (5 to 10 cm), placed on existing pavement surface with cracks in wearing course, during the first year of performance. Most extensively cracks appear in spring and autumn, and open in winter. Cracks have different length, width and depth. At high temperatures in summer period “young” minor cracks can partly be rolled by wheels of vehicles at wheel path due to bitumen softening in asphalt concrete.

Practice of repair works shows that crack sealing at early stage of their initiation allows us to avoid premature pavement deterioration and increase its service life. Particular significance has crack sealing prior to beginning of precipitations in autumn as moisture penetration in pavement layers through cracks in surface layer and then in subgrade soil accelerates premature deterioration of the whole structure.

In severely continental climate of Ukraine surface of asphalt pavements in summer can have a temperature up to 60 – 65 $^{\circ}$C, and up to minus 30 $^{\circ}$C in winter, which requires from materials for crack sealing special properties as heat resistance and flexibility at low temperatures.

In Ukraine sealing of cracks with polymer modified bitumen sealants and hot applied mastics in asphalt pavements is applied, allowing block access of moisture to lower pavement layers and increase its durability. Petroleum road bitumen, modified with plasticizer, is used as base for production of bitumen-polymer sealants. Combination of plasticized bitumen and SBS-type polymer, and cationic polymer latex allows to obtain sealant characterized by both high elasticity, flexibility at low temperatures and heat resistance. Addition of mineral filler to the composition of bitumen-polymer sealant gives us bitumen-polymer mastic.

* Corresponding author. Tel.: +38-097-350-84-75.
E-mail address: ktsyrkunova@yahoo.com

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.028

Results of research of different filler influence on heat resistance, elasticity, flexibility and performance of polymer modified mastics at low temperatures have been highlighted in the paper. Influence of temperature of asphalt pavement on strength of adhesive interaction with polymer modified mastic has been determined.
Experience of practical implementation of techniques of crack sealing in asphalt pavements on motor road network in Ukraine indicates that technique of filling of beforehand prepared "reservoir" with hot bitumen-polymer sealant or mastic with overband on the surface of asphalt pavement results in the highest impermeability of crack, compared to flush filling of "reservoir". To increase durability it is important that the "reservoir" created by milling of asphalt pavement had square or rectangular cross-section and passed through crack. Technological sides of practical implementation of techniques of crack sealing in asphalt pavements are covered in the paper.

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: Asphalt pavement; crack; sealant; mastic; repair; bitumen; polymer; filler; overband

1. Introduction

In climate conditions of Ukraine materials in road pavements are subject to freezing in winter and thawing in spring. In winter stiffness of road pavement increases due to water freezing in granular base and subgrade as well as increase of bitumen film viscosity in bituminous materials. After spring thawing materials in pavement layers become saturated as a result of frozen moisture thawing. Subgrade soil is waterlogged which decreases its bearing capacity. Period of road pavement weakness depends on depth of freezing, soil type, degree of water saturation and condition of water drainage. Weak road pavements cannot carry design loads and in this condition they accumulate most part of defects, significant number of which can appear as cracks in asphalt concrete pavement layers.

Experience proves that cracks are one of the most widespread modes of deterioration of asphalt pavements in Ukraine. Main cause of asphalt pavement cracking is tensile stress due to loads from vehicles as well as abrupt temperature decease and its significant gradients in winter. Observations indicate that joint influence of the above-mentioned factors results in increased rates of crack formation and propagation in asphalt pavements, which can appear during first year of performance. Experience shows that first of all asphalt pavements suffer from random transverse cracking. In old pavements strengthened with overlays reflective cracks can appear on the surface of new layer already in few years of service. The cracks have different length, width and depth. Most extensively cracks appear in spring and autumn, and open in winter. In summer cracks can decrease its width due to asphalt pavement expansion. At high temperatures in summer period "young" minor cracks can partly be rolled by wheels of vehicles at wheel path due to bitumen softening in asphalt concrete.

Cracks significantly influence durability of road pavement in general, as they break integrity of layers dividing them into separate blocks. As a result load from vehicles transfers to significantly weakened structure and is distributed over smaller area. New cracks have almost no influence on traffic conditions until crack develops into pothole. When wheels of vehicles ride on crack edges its sides move vertically relative to one another. Edges and walls of crack, saturated with water, break down and gradually crack turns into pothole, which allows free water penetration to base and subgrade and causes premature deterioration of the whole pavement structure. Potholes are widespread secondary mode of deterioration in areas of late crack sealing. Repair of potholes and cracks with broken edges can be much more expansive than crack sealing at the beginning of its development.

Practice of repair works shows that crack sealing at early stage of their initiation allows us to avoid premature pavement deterioration and significantly increase its service life. Particular significance has crack sealing prior to beginning of precipitations in autumn that can prevent moisture penetration in sub-base through cracks in pavement and then in subgrade soil.

2. Crack sealing materials

In many countries crack sealing with hot-applied bitumen-polymer sealants or mastics is in practice. Mastics differ from sealants by presence of fillers in their composition. Today many foreign companies are main suppliers of sealants and mastics in Ukraine. Bitumen polymer compositions are considered to be the best ones. In cold climate, according to Masson et al. (2000), the most appropriate are bitumen-polymer sealants and mastics characterized by 90-130 mm^{-1} penetration at 25 ºC and viscosity less than 15 Pa·s at crack sealing. However, main characteristics, which significantly influence performance of the sealing material in crack, are deformability (cold resistance) at low temperatures and heat resistance at high service temperatures.

As main component petroleum bitumen is traditionally applied. To impart required properties to mastic bitumen is modified with polymers, filler and, if necessary, plasticizer. Mostly roofing and construction petroleum bitumen are recommended to manufacture bitumen-polymer sealants and mastics. Traditionally fine powdered materials, obtained by grinding mineral materials of different origin, or ground rubber crumb are used as fillers. The most widespread powdered fillers are kaolin, talc, talc-magnesite. To obtain quality mastics mineral fillers are required to be water resistant and chemically inert, they must not swell and cause chemical reactions in the composition of the mastic.

Dominating role in provision of the required properties of bitumen mastics plays polymer. The most widespread, as modifying additives to bitumen when manufacturing bitumen-polymer mastics, are thermoplastic elastomers (SBS type). It is known that, according to Zolotov et al. (2006), thermoplastic elastomers provide bitumen mastics with both high heat resistance and elasticity. Introduction of filler to bitumen-polymer sealant results in rather moderate increase in softening point. Plasticizer provides increase in deformability of the mastic at low temperatures. Research on influence of fillers on properties of bitumen mastics are covered in Gorshenina (1967), Zolotov et al. (2006) and Zolotov et al. (2007). It is well known that presence of powdered filler in composition of the sealant decreases its penetration and ductility. Owing to addition of filler we can observe decrease of shrinkage and creeping as well as cost reduction of the material as a result of increased volume. Mechanical strength of mastics significantly increases only when adding large amount of filler. However, addition of more than30 % of mineral filler causes deterioration of technological properties of the mastic.

In Ukraine demand for effective crack sealing materials for asphalt pavements increases year by year. Due to high cost of foreign mastics performance of works on crack sealing in asphalt pavements is significantly slowed down. On the other hand, main reason of restrained industrial production of quality mastics in Ukraine is insufficiently researched influence of their composition on main properties. Until now influence of different fillers on cold resistance and heat resistance of bitumen-polymer mastics on petroleum road bitumen is still understudied. This made authors to carry out the research studies, which results are given below.

3. Research results

In the research performed petroleum road bitumen, modified with plasticizer, SBS type thermoplastic elastomer, latex and different fine fillers were used as main components to produce bitumen-polymer mastics. Three fine mineral fillers used for the research (marked as B, K and G) differ by degree of fineness and mineral composition. To carry out comparative research ground rubber crumb was also used as filler.

Production of bitumen-polymer sealant (i.e. composition without filler) was performed at the plant in planetary type mixer as follows. Plasticized petroleum road bitumen was heated to 180 ºC. After that polymer was added to the bitumen and mixed at 175-185 ºC for 60 minutes. Then required amount of latex was added to the mixture and continued mixing for 20 minutes at 180 ºC. To obtain bitumen-polymer mastic filler was added to the composition at 180 °C and mixed in laboratory mixer for 10 minutes.

Research results of influence of different fillers on properties of bitumen-polymer mastics are shown in Tables 1 and 2. Analysis of research results indicates that bitumen-polymer sealant produced on plasticized road bitumen is characterized by both high softening point and elasticity, and low brittle point and flexibility at low temperatures. As can be seen from the results obtained, addition of the fillers to the composition of bitumen-polymer sealant causes change of its properties. Increase of mineral filler content in sealant composition leads to increase of its softening point, brittle point and flexibility at low temperatures, and decrease of needle penetration, ductility and elasticity. When content of different mineral fillers in sealant composition makes up 15% its softening point increases up to 4–8 ^{o}C and flexibility at low temperatures increases by no more than 9 ^{o}C. Flexibility at low temperatures for bitumen-polymer sealant makes up lower than minus 35 ^{o}C and for mastics with 15% of different mineral fillers not less than minus 25 °C by absolute value. The highest value of elasticity reduction (by 33 %) was obtained for sealant with mineral filler G (15%), and the lowest (by 3 %) for sealant with filler B (15%).

Table 1. Properties of bitumen-polymer mastics with filler B and K.

Property	No filler	Content of filler B (%)			Content of filler K (%)		
		5	10	15	5	10	15
Softening point, °C	106.0	108.5	109.0	110.0	108.0	109.5	110.6
Penetration, mm^{-1}, at 25 °C	68	60	57	51	62	59	56
Ductility, cm, at 25 °C	67	58	50	49	64	61	55
Elasticity, %	98	97	96	95	96	96	94
Brittle point, °C	>-40	>-40	>-40	-40	>-40	>-40	-40
Flexibility on mandrel 2 cm in diameter, °C	>-35	>-30	-30	-27	>-30	-30	-26
Specific gravity, kg/m^3	980	-	-	1080	-	-	1060
Flexibility, °C, after conditioning for:							
100 hours	>-30	>-30	-26	-25	>-30	-29	-25
200 hours	>-30	-28	-24	-22	-30	-28	-23
300 hours	>-30	-25	-22	-20	-26	-25	-21
Softening point, °C, after conditioning for:							
100 hours	106.3	108.7	109.4	110.3	108.2	109.7	110.9
200 hours	106.9	108.9	109.6	110.5	108.5	109.9	111.0
300 hours	107.1	109.1	109.9	110.8	108.8	110.2	111.2

Table 2. Properties of bitumen-polymer mastics with filler G and rubber crumb.

Property	No filler	Content of filler G (%)			Content of rubber crumb (%)			
		5	10	15	3	5	15	20
Softening point, °C	106.0	111.0	112.7	113.7	107.0	107.2	118.5	119.8
Penetration, mm^{-1}, at 25 °C	68	70	67	57	64	63	52	44
Ductility, cm, at 25 °C	67	45	41	34	-	-	-	-
Elasticity, %	98	97	75	65	-	-	-	-
Brittle point, °C	>-40	>-40	>-40	-40	-40	-40	-38	-38
Flexibility on mandrel 2 cm in diameter, °C	>-35	-35	-30	-27	>-30	>-30	-30	-26
Specific gravity, kg/m^3	980	-	-	1093	-	-	1140	-
Flexibility, °C, after conditioning for:								
100 hours	>-30	>-30	-27	-25	-	>-30	-28	-
200 hours	>-30	>-30	-24	-23	-	-30	-26	-
300 hours	>-30	-30	-22	-20	-	-29	-25	-
Softening point, °C, after conditioning for:								
100 hours	106.3	111.3	113.0	113.9	-	107.5	118.7	-
200 hours	106.9	111.5	113.2	114.1	-	107.9	118.9	-
300 hours	107.1	111.6	113.5	114.4	-	108.1	119.1	-

Among three fine mineral fillers under research the most increase of softening point was provided by filler G. This is related to higher fineness of the filler (total amount of particles retained on sieve 0.071 mm for filler B is 18%, K – 8% and G – 0%). The research results also prove that specific gravity of sealing material expectedly increases when adding mineral fillers to its composition.

Research results shown in Table 2 indicate that specific gravity of bitumen-polymer sealing material increases most of all when adding rubber crumb to its composition compared to the mineral fillers under research. As with mineral fillers when increasing content of rubber crumb in bitumen-polymer sealant composition its softening point, brittle point and flexibility at low temperatures increases, and penetration decreases. Rubber crumb as a filler gives the highest increment of softening point and the lowest increase of flexibility at low temperatures compared to the mineral fillers.

During the research influence of high temperatures on change of main properties by bitumen-polymer sealants and mastics was simulated by conditioning of samples 2 mm thick at 65 ^{o}C. Research results for bitumen-polymer compositions with different mineral fillers show that values of flexibility and softening point change moderately after 300 hours of the conditioning.

4. Crack sealing methods

Not least important factor of quality crack repair in asphalt pavements is crack sealing technology. According to Masson (2001), sealing of cracks in asphalt pavements 15-20 mm thick and wider is performed my means of their cleaning and subsequent mastic filling. However, cracks less than 15-20 mm are recommended to be routed. Experience of Kharkiv National Automobile and Highway University, obtained in Ukraine during scientific consultations on projects of crack sealing in asphalt pavements on motor roads of general use indicates that cracks 10 mm wide can also be sealed without routing. When routing crack (Fig. 1) recommended ratios are as follows: B:h=1:1, if B<10 mm and B:h = 2:1, if B>10 mm. To minimize area of sealing material being in contact with vehicle tires and avoid its pressing out of the rout maximum width of the rout shall be no more than 30 mm.

Routing is recommended to be performed to the full length of crack using routers with carbide cutter wheels. Main purpose of crack routing is to delete loose oxidized asphalt layer to the crack depth.

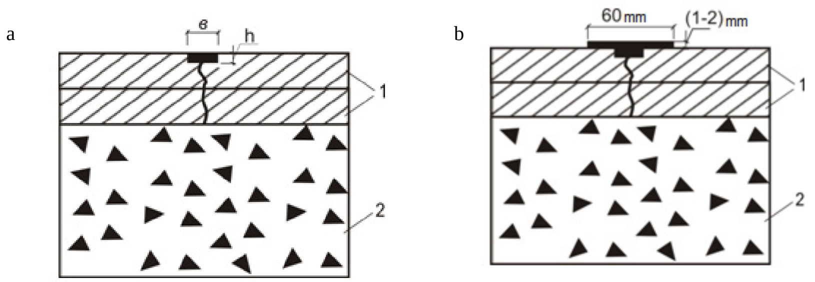

Fig. 1. Routed crack filled with bitumen-polymer sealant (a) flush with edges; (b) with overband of sealing material on the surface of asphalt pavement (1– asphalt concrete layers, 2 – base course).

Pouring of hot bitumen-polymer sealant in the prepared rout can also be carried out flush with pavement edges (Fig. 1a). Sealing of rout flush with edges is practical on sites where sealant can be damaged during removal of snow from the pavement surface.

Crack repair method when hot bitumen-polymer sealant is poured into the rout with overband on the asphalt pavement surface (Fig. 1b) provides the best crack tightness and durability of sealing material in crack repaired compared to sealing crack flush with adjacent pavement edges. It is important that crack rout had square or rectangular cross-section and was located in crack. Rounded bottom of the crack rout or V-shaped form of the rout will promote sealant debonding.

For high quality of crack sealing strong adhesion between sealing material and crack edges or crack rout created by crack routing is very important. It is required to clean and dry the crack carefully as even small amount of dust and moisture in crack prevents reliable adhesion of sealing material to crack edges. To clean routed crack from dust and loose asphalt concrete blowing with compressed air (Fig. 2a) from compressor at pressure not less than 0.6 MPa is required. It is also necessary to remove loose material from pavement surface near routed crack as much as possible to protect it from dust immediately before pouring bitumen-polymer sealant. When air temperature is below 5-10 °C it is necessary to use heat lance to remove moisture and heat the rout. Compressed air temperature of heat lance shall be below 500 °C to effectively remove moisture without overheating of the rout. Overheating of crack edges can result in reduction of adhesion between bitumen-polymer sealant and asphalt concrete surface in the rout.

To increase adhesion of bitumen-polymer sealant to asphalt pavement surface in rout it is practical to apply liquid polymer primer.

Fig. 2. Crack sealing stages: (a) preparation of crack with heat lance; (b, c) filling crack with bitumen-polymer sealing material; (d) dusting

Basic technological operation when sealing cracks is filling it with hot bitumen-polymer sealant (Fig. 2b,c). To minimize negative influence of high temperature on bitumen-polymer sealant properties it should be heated to lower temperature recommended by the material supplier. For example, if recommended sealant heating temperature is 180-195 ^{o}C, it should be heated to 180 ^{o}C. Heating to higher temperature is necessary only in cases when viscosity of bitumen-polymer sealant is more than 15 Pa·s at 180 ^{o}C. It is necessary to avoid long heating period for sealant as well as cooling and reheating. Application of melting kettle with small reservoir or operation of semifilled reservoir will prevent long heating. Sealing equipment shall provide uniform heating of all sealant volume and maintain working temperature, stable sealing material supply under pressure in crack with minimum temperature loss and continuous automated control of working temperature.

Filling of the routed crack with bitumen-polymer sealant with overband on asphalt pavement surface shall be performed using specialized machines with crack sealing shoe in the shape of iron or rectangle (without bottom) 50-60 mm wide. Thickness of sealing material in area of overband on asphalt pavement surface shall not exceed 1-2 mm.

Immediately after filling of the rout with bitumen-polymer sealant its surface shall be dusted with dry fine sand or siftings in order to avoid sticking of sealant to wheels of vehicles (Fig. 2d). Thin paper placed on the sealant surface can also protect from sticking.

The best period for crack sealing is late summer to middle autumn when pavement temperature allows crack opening to the width between maximum and minimum. Sealing cracks when pavement temperature is average, sealant takes smaller stresses and thus separation of sealant from the surface is more unlikely. Similar temperatures can be observed in spring, but at that time pavement near crack is waterlogged. However, if moisture content of pavement is acceptable, works on crack sealing can be performed also in spring.

5. Conclusions

Research performed allows us to state that petroleum road bitumen can be used as basic component to manufacture bitumen-polymer sealants and mastics.

To reduce brittle point and flexibility at low temperatures of sealants and mastics it is necessary to add plasticizer, and to increase heat resistance – thermoplastic elastomers of SBS type, latexes, mineral fillers or fine rubber crumb.

Crack repair method when hot bitumen-polymer sealant is poured into the square or rectangular rout with overband on the asphalt pavement surface provides the best crack tightness and durability of sealing material in crack repaired compared to sealing crack flush with edges.

For high quality of crack sealing strong adhesion between sealing material and crack edges or crack rout created by crack routing is very important. This requires careful cleaning and drying of the crack.

To increase adhesion of bitumen-polymer sealant to asphalt pavement surface in rout it is practical to apply primer.

The best period for crack sealing is the one when pavement temperature allows crack opening to the width between maximum and minimum.

References

Gorshenina, G.I., Michailov, N.V., 1967. Polymer-bitumen isolation materials. Nedra, Moscow, pp. 239 (in Russian).

Masson, J-F., Lacasse, M.A., 2000. A review of adhesion mechanisms at the crack sealant asphalt concrete interface, in Durability of Building and Construction Sealants, A. Wolf Ed., RILEM, Paris, pp. 259–74.

Masson, J-F., 2001. Sealing Cracks in Asphalt Concrete Pavements. Institute for Research in Construction, National Research Council of Canada, Construction Technology Updates. – No.49, pp. 4.

Zolotov, M., Zhdanyuk, K., Zhdanyuk, V., 2006. The influence of technological factors on bridge deck waterproofing when laying hot asphalt concrete protective and wearing courses // Ist Polish Road Congress. Warszawa, pp. 491-498.

Zolotov, M., Zhdanyuk K., 2007. Influence of powder and fiber fillers on properties of bituminous waterproofing mastics // Resource efficient materials, structures and buildings: Proceedings. Rivne: NUVGP, issue 15, pp. 53-58. (in Ukrainian).